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## BACK SURFACE REFLECTORS FOR SOLAR CELLS

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## BACK SURFACE REFLECTORS FOR SOLAR CELLS

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### ABSTRACT

Sample solar cells have been fabricated to study the effect of various back surface reflectors on the device performance. They are typical 50  $\mu\text{m}$  thick, space quality, silicon solar cells except for variations of the back contact configuration. The back surfaces of the sample cells are polished to a mirror-like finish, and have either conventional full contacts or grid finger contacts. With the back contact in a grid finger pattern, one can easily separate reflector formation from back contact fabrication. Measurements and evaluation of various metallic back surface reflectors, as well as cells with total internal reflection, are presented. It is found that back surface reflectors formed using a grid finger back contact are more effective reflectors than cells with full back metallization and that Au, Ag, or Cu are better back surface reflector metals than Al.

### INTRODUCTION

In order to increase the current output of space solar cells, various techniques have been tried. These include back surface reflectors (BSR) and texturized front surfaces. The benefits of back surface reflectors are well known (1,2). First, the BSR reflects the infrared light that would normally be adsorbed in the rear contact subsequently raising the temperature of the cell and thereby reducing the cell voltage. Second, the BSR doubles the path length of light in the cell. This is especially important in ultra-thin (50  $\mu\text{m}$ ) solar cells and can produce current densities equivalent to 100  $\mu\text{m}$  thick cells.

The absorptance of texturized surface cells is typically high which causes these cells to operate at temperature much higher than their planar counterparts. This increase in temperature eliminates the performance advantage gained by texturizing. If some way could be found to decrease the absorptance, substantial performance gain could be achieved. Knowing that texturized front surface refracts light rays to exceed the critical angle so that total internal reflection takes place at the back surface (3), polished bare silicon should provide the best back surface reflector for a textured front surface cell. The addition of a metallic BSR would be expected to reduce the reflectivity of

this interface hence lead to an increase in absorptance.

Recent work of Iles and Khemthong (1) discussed cell variables which affect reflection and thus the absorptance,  $\alpha_s$ , of a solar cell. They found that a polished back surface with an aluminum contact applied at a low temperature gave the lowest absorptance value. However, aluminum metallization sintered at such low temperatures did not always produce a good ohmic contact and thus led to reduced cell output through increased series resistance. On the other hand, when the metallization is heated at temperatures sufficiently high to achieve a good ohmic contact, the sharp metal-semiconductor interface is disturbed and the effectiveness of the metallization as a back surface reflector is reduced.

If application of the BSR could be separated from the back contact formation, the problems mentioned above could be overcome and significant advantages would result. A simple method of separating back contact formation from BSR formation is presented here. This approach uses back contacts in a grid finger pattern with a metal BSR applied between the grids after contact sintering. Absorptance, reflectance and spectral response measurements were made on cells with different BSR metals and with and without a texturized front surface. It is the purpose of this paper to present results of an experimental study to determine the effect of various metallic back surface reflectors on planar and texturized surface cell absorptance and spectral response using this alternative configuration.

### EXPERIMENTAL DESCRIPTION

#### Cell Preparation

The thickness of cells used in this study was nominally 50  $\mu\text{m}$ . The smoothness of the polished back surface was preserved by using gaseous boron diffusion to form the back surface field. A mirror-like back surface finish was preserved for all samples except the areas directly under the sintered metal contacts. Of course, the mirror finish could not be preserved on cells with full back contacts due to the sintering process. Both textured and planar front surface cells were studied and all cells were coated with a multiple layer antireflection coating. Each surface treatment group con-

tained cells with full back contacts and cells with grid finger back contacts. The grid finger rear contact utilized in this study had 12 fingers per 2- by 2-cm cell. To determine if the fill factor was effected by the number of grid fingers one set of cells was prepared with 20 grid fingers for the rear contacts. It turned out that the additional collecting fingers improved the fill factor only slightly.

The cells used in this study were designated with code letters as follows:

- PF - Planar front surface, full back contact with aluminum BSR formed under low temperature sintering
- PL - Planar front surface, line finger back contact (12 grid fingers)
- TF - Textured front surface, full back contact with Aluminum BSR formed under low temperature sintering
- TL - Textured front surface, line finger back contact (12 grid fingers)
- TD - Textured front surface, double line finger back contact (20 grid fingers)

The PF and TF cells with full back contact and BSR used as baseline cells were typical 50  $\mu$ m thick space quality solar cells. The BSR and back contact were formed under the optimum low temperature heat treatment condition described by Iles and Khemthong.

Two cells from each of the PL set and TD set were used as control cells. They remained unchanged throughout the experiment. They also served to provide comparison between the different configurations. After initial measurements, eight PL cells and four TD cells were used for experiments with the different metal reflectors. All reflector metals (Al, Cu, Ag, Au) were deposited by vacuum evaporation and were around 1500  $\text{\AA}$  thick. No additional sintering of the metallic reflector layers was done.

#### Absorptance Measurements

A Cary 14 spectrophotometer equipped with an integrating sphere was used to measure the spectral reflectance (diffuse and specular) over the 0.25 to 2.5  $\mu$ m range. A relative ratio measurement technique was used. A clean  $\text{MgCO}_3$  surface was used as reference for calibration. The spectral reflectance curve was then weighted according to the AMO spectrum and integrated across the entire spectral range to obtain reflectance of the sample under AMO illumination. Absorptance of the sample was obtained by simply subtracting the reflectance value from unity.

A special sample holder was made to simulate the absorptive rear contact of non-BSR conventional cells. It provided a blackened cavity on the back side of the sample so that light passing through

any of the PL cells would not be reflected back into the sample from the holder.

#### RESULTS AND DISCUSSION

The change in absorptance between PL cells with no BSR layers and PL cells with various metallic reflectors results primarily from the difference in reflectance in the infrared region. The increased reflectivity of cells with back surface reflectors is clearly shown in Figs. 1 to 4. Under normal incidence illumination, cells with a textured front surface refract light rays to exceed the critical angle so that total internal reflection takes place at the back surface. However, if a metal film is deposited on the back surface of textured cells, internal reflection does not occur because the low index of refraction medium, air, is replaced by a medium with a high index of refraction. Comparisons between textured front surface cells with and without a metal BSR are actually a comparison between total internal reflection and a metal BSR. Since a reflector based on internal reflection is the best reflector possible, no material BSR can be expected to improve upon the effectiveness of total internal reflection. Figures 5 and 6 confirm this expectation.

The average values of the solar spectral absorptance,  $\alpha_s$ , of all samples are listed in Table I. They are grouped according to type and BSR material. The primary baseline cells (PF), have full aluminum back contacts with low temperature sintering as the BSR. The 0.683 value of  $\alpha_s$  obtained with these samples is very close to the best case measurement of  $\alpha_s$  (0.69) reported by Iles and Khemthong (1) with equivalent samples. The average  $\alpha_s$  of all ten planar front surface cells (PL) without metal BSR is 0.787. This is also in close agreement with the 0.797 value presented in Ref. 1 for the aluminum BSF cell or the 0.78 value for typical BSF cells without a BSR. It can also be seen from Table I that a gridded rear contact covered with an aluminum BSR can reduce the absorptance of a PL cell from 0.791 to 0.672, a reduction of 0.119 in  $\alpha_s$ . Comparing the data on PL\* and PF\* we get an approximate reduction in  $\alpha_s$  of 0.103 with the aluminum BSR formed by low heat sintering. This clearly demonstrates the virtue of avoiding the heat sintering in BSR formation. Using the same technique, silver, gold, or copper reflectors reduce  $\alpha_s$  even more. For example, Table I shows the reduction of  $\alpha_s$  for PL cells with Ag, Au, or Cu reflectors of 0.148, which corresponds to a reduction in cell operating temperature in space of 15° C (1).

Categorically, texturized front surface cells (TF, TL, and TD) have the highest values of absorptance, around 0.889-0.907. As mentioned above, on cells with a texturized front surface, adding a BSR of any material on the polished back surface results in replacing the near perfect internal BSR with a less effective BSR. This tends to decrease the reflectance slightly, and hence slightly increase the absorptance of the cell. The absorptance data on TD cells in Table I reinforce the results shown in Figs. 5 and 6 and confirm that addi-

tion of a metallic BSR will not reduce the  $\alpha_s$  of textured surface cells.

In their report, Iles and Khemthong also made an estimate on the practical lower limit of  $\alpha_s$  for silicon solar cells. The estimate, 0.63, was obtained by combining the highest reflectance values for the short (0.25-0.5  $\mu\text{m}$ ) and long (1.0-2.5  $\mu\text{m}$ ) wavelength region of individual cells with various covers and surface finishes while maintaining a typically low reflectance for the medium wavelength (0.5-1.0  $\mu\text{m}$ ) region. The highest reflectance value they obtained was with a back surface finish similar to the cells labelled PF in this study. Based on the above analysis, the aluminum BSR on PL cells should be better than that on PF cells. Comparing the spectral reflectance curves in Figs. 1 to 4, the reflectance value of a gold, silver, or copper BSR is generally 0.05 to 0.1 higher than aluminum in the long wavelength region. Since the long wavelength portion of the solar spectrum accounts for one third of the total energy, this study indicates that the 0.63 practical lower limit of  $\alpha_s$  can be further reduced by 0.02 to 0.03 units. Considering that no effort has been expended in optimizing any cell parameters or refining the rear contact grid finger pattern in this study, and that the best single cell measurement gave an  $\alpha_s$  of 0.634 (PL with a silver BSR), it is now estimated that the practical lower limit of  $\alpha_s$  is approximately 0.60 for silicon solar cells.

Recent work of Rasch, Roy, and Tentscher (2) indicated that reflectance measurement at a single wavelength (1.5  $\mu\text{m}$ ) could be used as an indicator of the solar cell absorptance  $\alpha_s$ . This study supports this finding. However making measurements with the Cary 14, 1.5  $\mu\text{m}$  is not a convenient wavelength to use when the gain had to be changed near 1.5  $\mu\text{m}$ . This prompted us to investigate whether reflectance measurement at other wavelengths could also serve as an indicator of the value of  $\alpha_s$ . For comparison purposes, the total absorptance,  $\alpha_s$ , of all PL samples is plotted against the spectral reflectance measured at three different wavelengths (1.2, 1.5, and 1.8  $\mu\text{m}$ ) in Fig. 7. All three plots appear linear, thus it would seem that one can choose to use the spectral reflectance measurement at any wavelength between 1.2 and 1.8  $\mu\text{m}$  as a simple indicator of the effectiveness of a solar cell BSR.

Spectral response measurements were made to determine the effect of the BSR on the performance of PL type cells. A change in the red response is expected due to a doubling of the optical path length of the long wavelength photons. Figure 8 shows the improved red response of a PL cells with a copper BSR on its polished back surface. For textured front surface cells, a slight decrease in red response was also observed when a metal BSR was added.

#### CONCLUSIONS

1. An absorptance reduction of 0.148 in planar silicon solar cells has been demonstrated for metallic back surface reflectors that were deposited over sintered back contact fingers. This corre-

sponds to a decrease of 15° C of cell operating temperature.

2. Gold, silver, and copper are better back surface reflectors than aluminum.

3. Adding a metal reflector on the polished back surface of a textured front surface cell cannot improve the cell absorptance or reduce its operating temperature. This indicates that internal reflection at the back surface is the primary reflection mechanism in textured front surface cells.

4. This study indicates that a minimum absorptance value around 0.60 can be achieved for silicon solar cells.

5. Measurement of cell reflectance at a single wavelength between 1.2 and 1.8  $\mu\text{m}$  can be used to estimate the solar cell absorptance.

#### REFERENCES

1. P. A. Iles and S. Khemthong, "The Alpha Factor-Controlling Solar Cell Absorptance," The Conference Record of the Thirteenth IEEE Photovoltaic Specialists Conference, 1978, New York: IEEE, 1978, pp. 327-332.
2. K.-D. Rasch, K. Roy, and K.-H. Tentscher, "Advanced Thin Silicon Solar Cell with Controlled Optical Absorptance," 2nd E. C. Photovoltaic Solar Energy Conference Proceedings, April 23-26, 1979, West Berlin, R. Van Overstraeter and W. Palz, Eds. Dordrecht: Reidel, 1979, pp. 205-212.
3. R. A. Arndt, J. F. Allison, J. G. Haynos, and A. Meulenber, Jr., "Optical Properties of the COMSAT Non-Reflective Cell," The Conference Record of the Eleventh IEEE Photovoltaic Specialists Conference, 1975, New York: IEEE, 1975, pp. 40-43.

TABLE I. - AVERAGE VALUES OF INTEGRATED SPECTRAL

ABSORPTANCE  $\alpha_g$ 

| Sample type | Metal back surface reflector | Numbers of samples | Average spectral absorptance, $\alpha_g$ |                |
|-------------|------------------------------|--------------------|--|----------------|
|             |                              |                    | Without metal BSR                        | With metal BSR |
| PF*         | Al                           | 2                  |  | 0.683±0.001    |
| PL**        | None                         | 2                  | 0.786±0.003                              |                |
| PL          | Al                           | 2                  | 0.791±0                                  | 0.672±0.004    |
| PL          | Ag                           | 2                  | 0.785±0.005                              | 0.639±0.005    |
| PL          | Au                           | 2                  | 0.785±0.002                              | 0.638±0.001    |
| PL          | Cu                           | 2                  | 0.791±0.003                              | 0.643±0.001    |
| TF*         | Al                           | 2                  |  | 0.899±0.007    |
| TL          | None                         | 2                  | 0.895±0.002                              |                |
| TD**        | None                         | 2                  | 0.899±0.003                              |                |
| TD          | Al                           | 1                  | 0.902                                    | 0.907          |
| TD          | Ag                           | 1                  | 0.893                                    | 0.895          |
| TD          | Au                           | 1                  | 0.895                                    | 0.893          |
| TD          | Cu                           | 1                  | 0.889                                    | 0.892          |

\*Baseline cells.

\*\*Control cells.

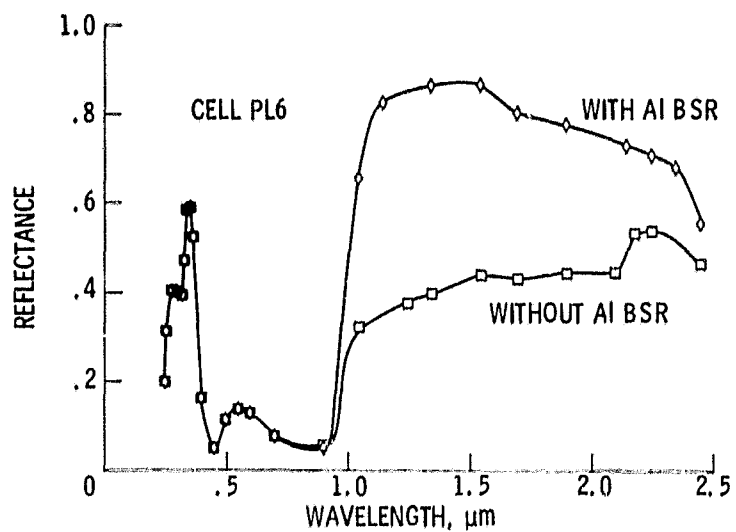


Figure 1. - Effect of aluminum back surface reflector on spectral reflectance of planar cell.

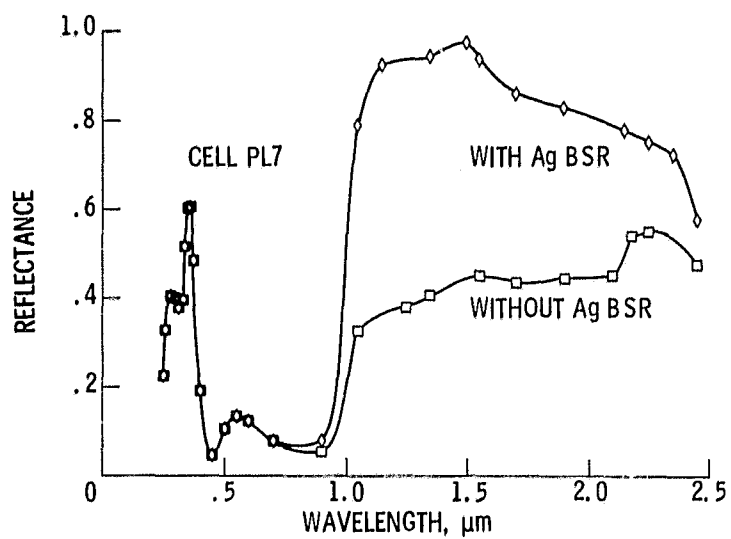


Figure 2. - Effect of silver back surface reflector on spectral reflectance of planar cell.

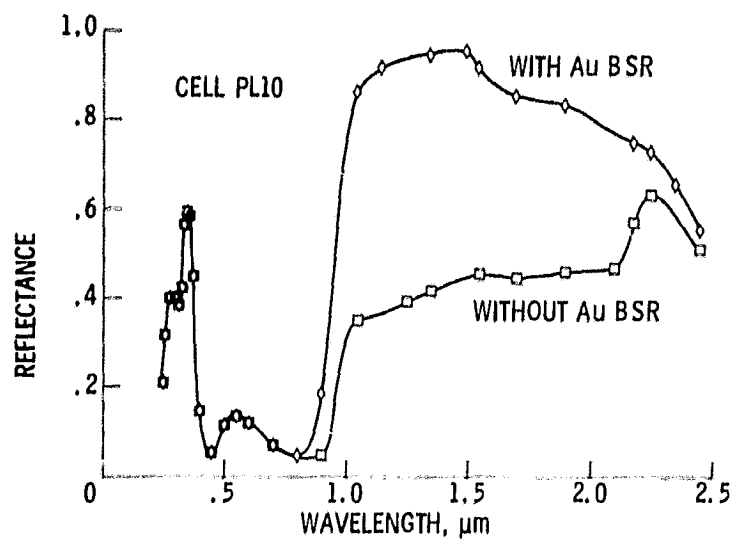


Figure 3. - Effect of gold back surface reflector on spectral reflectance of planar cell.

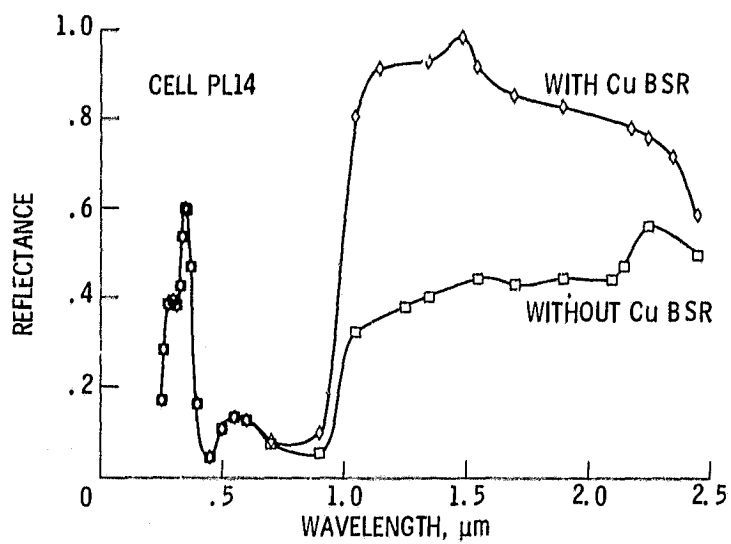


Figure 4. - Effect of copper back surface reflector on spectral reflectance of planar cell.

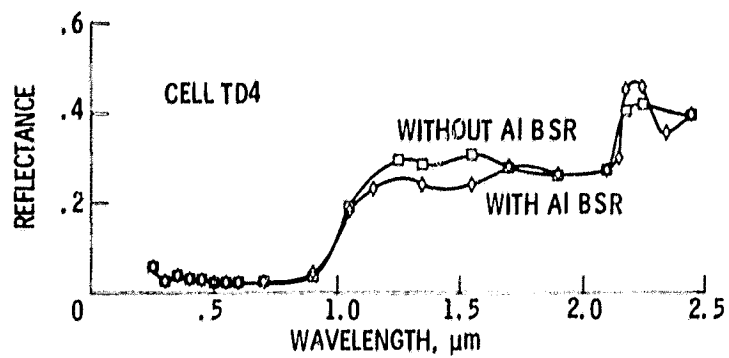


Figure 5. - Effect of aluminum back surface reflector on spectral reflectance of texturized cell.

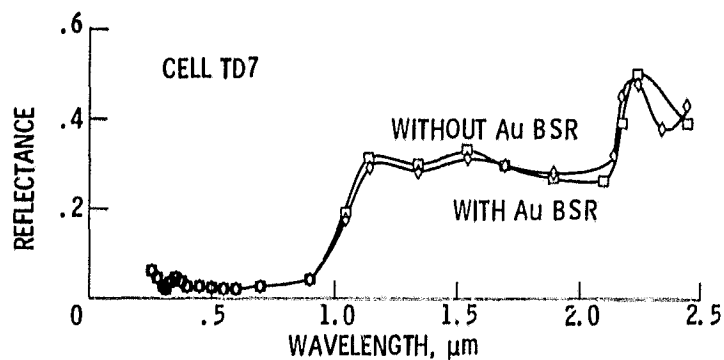


Figure 6. - Effect of gold back surface reflector on spectral reflectance of texturized cell.

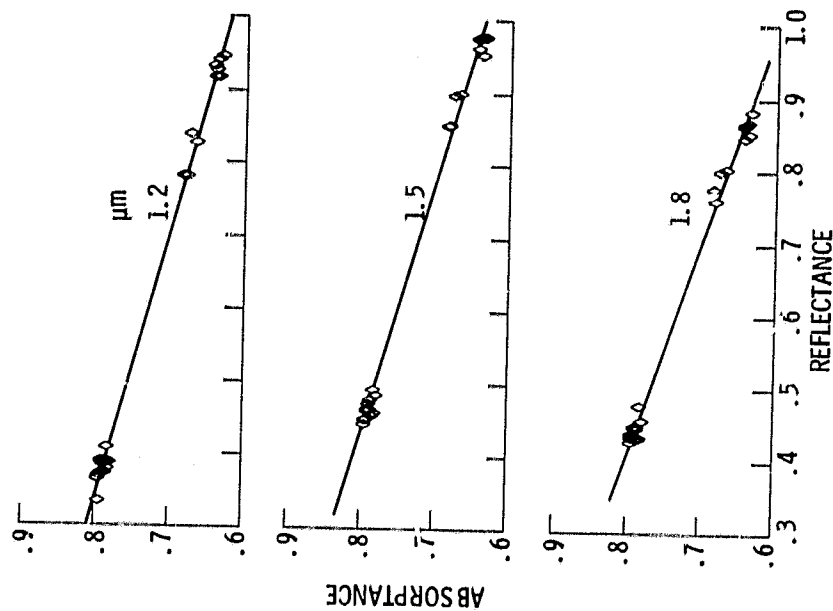


Figure 7. - Absorbance versus reflectance measured at 1.2, 1.5, and 1.8  $\mu\text{m}$ , respectively, for all planar cell samples.

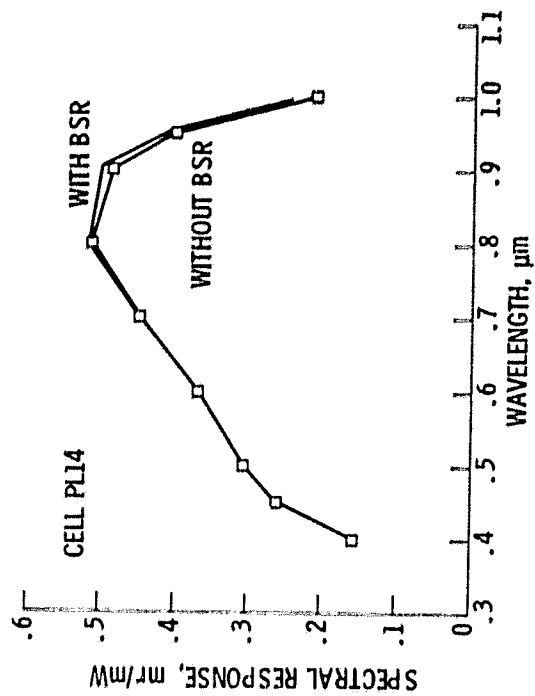


Figure 8. - Effect of copper BSR on spectral response of a planar cell.

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